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## HYDROLIGHT 3.1 USERS' GUIDE

Final Report

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13. ABSTRACT (Maximum 200 words)  HYDROLIGHT is a radiative transfer numerical model that computes spectral radiance distributions and related quantities for natural water bodies. Version 3.0 is the most general version of the HYDROLIGHT model. Version 3.1 of the model is a standardized version of the code, which is designed to be easy to run. Version 3.1 comes with a separate interactive front-end program that queries the user for input and then creates the files necessary to run the HYDROLIGHT code itself. Several options in the general Version 3.0 model are set to default values in the 3.1 code, in order to simplify the user-supplied input. Various files are in ASCII format, so that they are machine independent. The standard printout is tailored to remote-sensing applications.  This report documents only the interactive front-end program and the modifications made to the Version 3.0 code, which itself is fully documented. Users needing the full power of the HYDROLIGHT model can continue to run Version 3.0.				
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## 1. INTRODUCTION

HYDROLIGHT is a radiative transfer numerical model that computes radiance distributions and derived quantities for natural water bodies. In brief, this model computes from first principles the time-independent radiance distribution within and leaving any plane-parallel water body. Input to the model consists of the absorbing and scattering properties of the water body, the nature of the wind-blown sea surface and of the bottom of the water column, and the sun and sky radiance incident on the sea surface. Output consists both of archival printout and of files of digital data, from which graphical or other analyses can be performed.

Version 3.0 of the HYDROLIGHT code (henceforth called H3.0) was released in March 1995; that code is fully documented in Mobley (1995). H3.0 is the most general version of the HYDROLIGHT code and is designed to give the user great flexibility in specifying the details of a HYDROLIGHT simulation. For example, output can be requested at any set of depths, in order to get increased depth resolution near features such as microlayers within the water column; the wavelength bands can be non-uniform, in order to get increased wavelength resolution near features such as the chlorophyll fluorescence peak near 685 nm; the water absorption and scattering properties can be built up from any number of components; and so on. However, because of this generality, the user must supply a great deal of input to H3.0 when setting up a computer run. This is not an easy task, especially for users who are using H3.0 for the first time or who are not experienced scientific programmers. Moreover, setting up H3.0 requires that each user perform a number of one-time computer runs to generate files of surface information for different wind speeds and of discretized phase functions. These files are binary in order to minimize their size and read-in times, and therefore they cannot be ported from one computer to another.

Experience has shown that many users of HYDROLIGHT use it in only a simplified form and do not need its full generality. For example, for remote-sensing applications only the water-leaving radiance or the remote-sensing reflectance is of interest; the light field within the water may be of little or no interest. Some users just wish to make quick simulations at a single

wavelength, perhaps assuming the water to be homogeneous and using absorption and scattering coefficients read in at run time (rather than computed in a user-supplied subroutine). For such users, and for users working with HYDROLIGHT for the first time, convenience of running the HYDROLIGHT model is an important consideration.

HYDROLIGHT version 3.1 (H3.1) was developed with convenience as the primary goal. Various options are set to default values. For example, the wavelength bands are taken to be equal in size, and in-water output is given only at equally spaced depths between the surface and the depth of greatest interest. Files containing information about the sea surface for various wind speeds and files with various discretized phase functions are now created in ASCII format. This allows these files to be distributed with the H3.1 code, so that users no longer have to create their own versions of such files (although they can still do so if they wish).

Most importantly, a separate front-end program has been written to give users an interactive interface for specifying an H3.1 run. This interface, which is itself just a Fortran program, asks the user various questions about the simulation. These questions ask the user to pick a wind speed from a list of allowed values, to specify the solar angle and cloud cover, and so on. Certain defaults, such as the wavelength range and bandwidth, are displayed and the user is allowed to accept or change the default values. Other defaults, such as the number of depths where output is given, can be easily changed by editing the front-end program code. Users can therefore tailor the front-end program to fit their own requirements.

The front-end program uses the user's responses to write two files. The first file is the "input" file containing the information (as described in Section 4.2 of the H3.0 Users' Guide) required by H3.1 to perform a simulation. The second file is the "script" or "run" file that actually submits the H3.1 run to the computer. This script file attaches the appropriate sea-surface and phase function files, runs the H3.1 code, and then saves the output files for later examination.

## 2. OVERVIEW OF HYDROLIGHT 3.1

HYDROLIGHT Version 3.0 remains the general version of the HYDROLIGHT code and should still be used when the full power of HYDROLIGHT is required. This section describes only the relatively minor changes made to H3.0 code in order to create Version 3.1. The changes to H3.0 were purposely kept to a minimum, so that the H3.0 Users' Guide (Mobley, 1995) would remain valid as the detailed reference for users of H3.1. The discussion here presumes that the reader is already somewhat familiar with H3.0, and that the H3.0 Users' Guide is available for cross-reference.

### 2.1 Modifications to Part 1

The HYDROLIGHT 3.0 Part 1 code was changed in several ways. For many users, it will no longer be necessary to run Part 1, since the needed output files from Part 1 can now be distributed along with the code. The modifications to Part 1 consist primarily of using a standard quad partitioning scheme, of using azimuthally isotropic surface wave-slope statistics, and of writing the final output files in ASCII format.

Part 1 of HYDROLIGHT computes the four quad-averaged radiance transfer arrays for the air-water surface, using Monte Carlo simulations as described in Mobley (1994, Section 4.7). These computations require the specification of a quad partitioning scheme and a wind speed. A quad partitioning divides the set of all directions into quads, which are cells defined by lines of constant polar angle  $\theta$  and constant azimuthal angle  $\phi$ . In H3.1, a newly defined "standard" quad partitioning is used. This partitioning has a 10-degree spacing in  $\theta$  and a 15-degree spacing in  $\phi$ , as shown in Fig. 1. The polar caps have a full angle of 10 degrees. The centers of the quads are therefore at  $\theta = 0, 10, 20, \dots, 80$ , and 87.5 degrees. The quads next to the "equator" cover only five degrees, from  $\theta = 85$  to 90 degrees. (However, when two five-degree quads adjacent to the equator are combined, this also gives a 10-degree resolution for the horizontal ( $\theta = 90$  degree) radiance, which is not computed explicitly.) This quad partitioning gives adequate angular resolution for most applications of HYDROLIGHT. (However, the other quad partitionings available in H3.0 are still available in H3.1, if users desire to use them. The

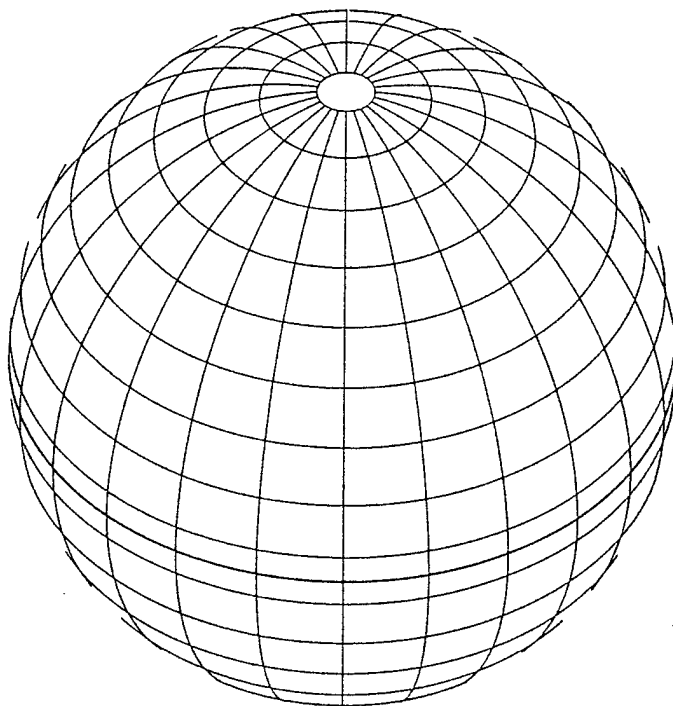


Figure 1. The standard 10 by 15 degree quad partitioning used in HYDROLIGHT Version 3.1.

standard partitioning just described is obtained by using  $M, N, iqpart = 20, 24, 4$  in the input to Part 1.)

The Cox-Munk capillary wave-slope parameters used in H3.0 give wave-slope statistics that are slightly different in the along-wind and cross-wind directions. This is a degree of sophistication in the simulations that is irrelevant to most users, since the surface wave state is seldom documented in detail. Therefore, azimuthally averaged slope statistics are used as the default in H3.1. This gives a surface that is azimuthally isotropic, and consequently it is no longer necessary for the user to specify the azimuthal angle between the downwind direction and the solar direction. (If desired, however, the anisotropic slope statistics can still be selected in subroutine inishl1. In this case, the front-end program should be modified to ask the user for the azimuthal angle  $\phi$ , as described in the H3.0 Users' Guide.)

The final output file from Part 1 is now written in ASCII format. Files corresponding to wind speeds of  $U = 0, 2, 5,$  and  $10 \text{ m s}^{-1}$  are distributed with the H3.1 code. These are the wind speeds available for selection when running the front-end program and are sufficient for most users. Users needing additional wind speeds can run the H3.1 Part 1 code, with the wind speed being specified just as described in the H3.0 Users' Guide, to generate files for the desired wind speeds. The front-end program can then be modified to add the new wind speeds to the list of allowed values.

These ASCII files require several times as much storage as the corresponding binary files created by H3.0. However, the ASCII files require less than 2 MB each, which is insignificant on most computer systems. (If desired, the output files can still be written in binary by setting the `iascii` flag to zero in the Part 1 code. If storage is limited, the ASCII files also could be stored as compressed files, with only a single file being uncompressed during a given H3.1 run.)

Finally, several internal files used in Part 1 have been made scratch files. These changes are transparent to users running Part 1.

## 2.2 Modifications to Part 2

Corresponding modifications have been made to H3.0 Part 2 in order to create H3.1 Part 2. First, of course, the surface transfer files created by Part 1 can now be read either as ASCII (the default for H3.1) or binary (as in H3.0). Likewise, when a phase function is discretized by running H3.1 in "discretization mode," which is done just as described in Section 4.1.7 of the H3.0 Users' Guide, the output file is now written as ASCII. Once again, this means that machine-independent files of phase function information can be distributed with the code. Two such files, one for pure water (file `pfpure`) and one for a typical particle phase function (file `pfpart`), are distributed with the H3.1 code. These files have the phase functions discretized for the standard 10 by 15 degree quad partition described above. Users wishing to discretize other phase functions can run H3.1 in discretization mode, just as is done with H3.0.

It must be noted that the `abscat` and `phasef` subroutines described in Section 4.1.1 of the H3.0 Users' Guide are still the same in H3.1. Thus, a user wishing to simulate a case 1 water



body with a given chlorophyll profile must still compile the executable program for H3.1 Part 2 using the `abscat` routine found on file `abcase1.f`, and the desired chlorophyll profile must be defined in subroutine `chlz`. Likewise, a user who wishes to discretize a one-term Henyey-Greenstein phase function for a given  $g$  parameter value must define the value of  $g$  in the `phasef` subroutine given on file `pfothg.f`, and then make sure that file `pfothg.f` is compiled into the executable program. The UNIX Makefile that carries out the compilation of the H3.1 code is almost identical to those for H3.0. The `abscat` and `phasef` subroutines, Makefiles, and related issues are discussed in detail in the H3.0 Users' Guide.

The final digital output file generated by Part 2 contains the complete set of information about the simulation including, among other things, the full radiance distribution at all depths and wavelengths where output was requested. This file is identical in H3.0 and H3.1 and is still written in binary form, which allows IDL (or other) plotting routines to read in the H3.1 output as quickly as possible for interactive graphical analysis of the computed output. There is no need for the final digital output files to be ASCII, since they are usually discarded after graphical analysis.

The default printout (as opposed to the digital output) in H3.1 has been changed slightly to give information that is of greater interest in remote-sensing studies. For example, the output now includes the incident sky radiance, the surface-reflected sky radiance, the water-leaving radiance, the total upward radiance, and the remote-sensing reflectance. These quantities are given as a function of  $\theta$ , but only in the  $\phi = 90$ -degree plane, which is at right angles to the sun's incoming rays. This geometry corresponds to that usually used in making remote-sensing reflectance measurements. This output can be tailored to a particular user's needs by setting parameters in the appropriate printout routines in Part 2 of the code (see, in particular, routines `readin2` and `pntrad`).

The default sky radiance model for H3.1 is the "real sky" model found on file `qarealsky.f` and described in the H3.0 Users' Guide. Users wishing to use other sky routines can load those routines in the Makefile, and then change the input requested by the front-end program accordingly.

### 2.3 Data files

The distributed H3.1 code contains a directory named data, which contains several ASCII files. The files with names like surfwind.5 contain the output from Part 1 for different wind speeds. Here, for example, the name surfwind.5 indicates that this file contains the information about the sea surface for a wind speed of  $5 \text{ m s}^{-1}$ . The files named pfpure and pfpart contain the discretized phase function for pure water and for particles, respectively. The actual phase functions are found on files pfpure.f and pfpart.f. The front-end program looks in this directory for the needed files. Therefore, if the user wishes to create additional files for other wind speeds or phase functions, they should be given names on the above pattern and stored in this directory.

After an H3.1 simulation is completed, the final binary file of digital data is given a descriptive name and moved into directory data. The name of this file is created by the front end, using the user's input.

## 3. THE FRONT-END PROGRAM

The distinguishing feature of Version 3.1 of the HYDROLIGHT code is the interactive front end. This program is simply a Fortran program that the user runs interactively. The user's responses to the questions asked by the front end are then used by the front end to write the input and script files needed to run HYDROLIGHT. This front end saves the user the effort of balancing the H3.0 Users' Guide on her knee while using a text editor to create the needed files. File management tasks such as attaching the Part 1 file corresponding to the desired wind speed are handled automatically by the front end. By running the front-end program, it is possible for a user who is almost completely unfamiliar with HYDROLIGHT to make a run.

The first question asked by the front end is whether the user wants the "standard" set of questions or the "full" set. The standard questions are designed to minimize the input requested from the user; various parameter values not requested are set to default values. The full set of questions asks for more input, which allows the user to override the default values and to have

more flexibility in specifying the HYDROLIGHT run. For example, by default in H3.1, the in-water printout is given only at five equally spaced depths in the water column. The standard questions therefore do not ask the user to specify the depths where printout is desired. However, the full questions allow the user either to accept the default depths or to read in a list of depths where printout is desired, just as is done with H3.0. The defaults – in this example, output at five depths – also can be changed by resetting the appropriate parameter values in the front-end program. Thus, users can set various defaults as desired for a given series of runs, and then answer only the standard questions in order to generate each particular run.

For multiple-wavelength runs, the front end takes the wavelength bands to be equal, with a default value of 10 nm. The default wavelength range covered is 350 to 700 nm (the full range allowed by the HYDROLIGHT "real sky" radiance model). Thus H3.1 computes the radiances averaged over the 35 wavelength bands 350 to 360, 360 to 370, ..., 690 to 700 nm. These default values can be changed when the front-end program is run. Users wishing to use unequal bandwidths can explicitly enter the required information into the HYDROLIGHT input file after the front-end program has terminated, the manner described in the H3.0 Users' Guide.

Other options, such as the inclusion of bioluminescence or inelastic scattering in the simulation, are set to default values which omit these effects from the run. These defaults are easily changed, either in the front-end program itself or by requesting the full set of questions.

In the distributed H3.1 code, the front-end program is found on file HFE2.f (for HYDROLIGHT Front End for Part 2) in directory part2, which contains the code for Part 2 of HYDROLIGHT. In order to set up and run the front-end program, the user should first edit file HFE2.f to set the default path names to values corresponding to where the various H3.1 directories are found on the user's computer. Other defaults also can be set to the user's preferences. After gaining some experience with the front end, users may wish to alter the particular questions asked, which is easily done by changing the appropriate statements in HFE2.f.

After making any changes to file HFE2.f, it is compiled via the command (on a UNIX system running Fortran 77)

```
f77 -o fe HFE2.f
```

(The "-o fe" option simply names the executable output file "fe" instead of the Fortran default name "a.out".) The front-end program is then executed simply by entering the command

fe

and then answering the questions. Subsequent runs of the front-end program are then made simply by re-entering the "fe" command; the front-end program needs to be recompiled only if further changes are made to file HFE2.f.

When the front-end program terminates, it tells the user the name of the script file that actually runs H3.1 (the exact script file name is generated from the user's input to the front end). Assuming for the moment that the script file name is "run.example", the user would then enter the command

run.example &

to submit the actual HYDROLIGHT run in the background.

Finally, it should be noted that after termination of the front-end program, the file of input information to H3.1 (named, perhaps, input.example) is left as an ASCII file in the part2 directory. Before submitting the H3.1 run, the user can, if desired, edit this input file to make any desired changes in the specification of the run to be made.

#### 4. REFERENCES

Mobley, C. D., 1994. *Light and Water: Radiative Transfer in Natural Waters*, Academic Press, San Diego, CA, 592 pages.

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